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Summary

The aim of this paper is to present the first results of a study about the dynamic behaviour of short bridges.
First we show why a specific treatment is to be carried out, and we look for the origins of this specific behaviour. After a correlation between calculations and measurements, the main parameters having an incidence on the behaviour of short bridges are brought to the fore.
Second a software is developed to create easily a finite element model of the bridge. This model take into account all the specificity of the short bridges: materials, type of deck, bearings with user conditions, track., and calculates the response for movable loads.

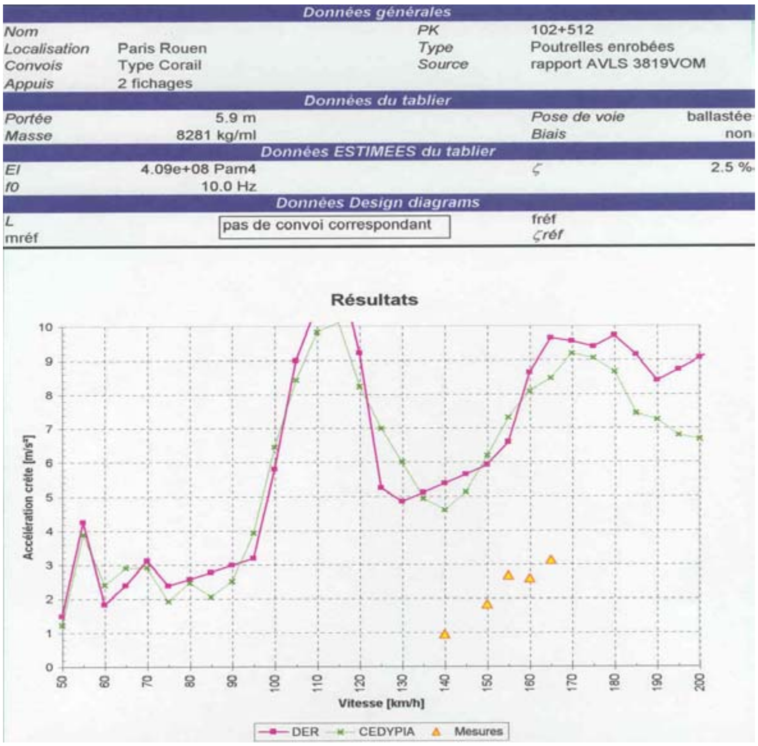
Key words: short bridge –interaction between the bridge, the vehicle and the track – rapid loading – bearing conditions

1. Foreword

Anticipating the dynamic behaviour of short bridges (l ≤20 m) is problematical.
They are the types of bridges most often encountered and which take the greatest load variations, a fact that renders them highly susceptible to dynamic structural loadings.
This susceptibility leads to two types of problems being, on the one hand, the design of new bridges on high speed lines and, on the other, establishing the capacity of existing bridges to accept greater speeds on conventional lines and, where the bridge is replaced, the necessary optimisation to respect the often difficult gauge conditions.
Here, we are concerned with the problem of maintaining or replacing these decks on existing lines, given that HSL lines provide a greater sizing freedom and that the problem has been virtually resolved by designing two track bridges.
In this type of one track bridge, the problem lies in modelling the structure, as the presence of the track as well as that of the vehicles has a substantial impact on the real dynamic characteristics. The same applies to the loading conditions and the behaviour of the ballast.
It is important to understand the interaction between the bridge, the vehicle and the track, and the effect of rapid loading.
This is why, to have a good behaviour prediction, it is important to carry out dynamic testing on these bridges.

2. Why a specific treatment for short bridges?

It is simply necessary to compare the measurements carried out on these types of bridges with the calculations carried out using data that have been estimated in a conventional manner:



Legend: Acceleration according to speed
Curves = calculations
Points = measure

Figure 1 : Comparison beetwen calculation and measurement

It is easy to note the great divergence that exists between the reality and the calculations.

When trying to establish a correlation between the calculations and the measurents, it rapidly becomes clear that normal methods are insufficient or result in certain parameter values being unrealistic.

Adjusting the stiffnes and the mass, as well as the damping, are insufficient to correctly characterise the behaviour of these structures.

If, following resetting on the 1st natural frequency, true acceleration values are found, it is the deformations that are incorrect and, conversely, if deformation values are used, then the acceleration values are not provided.

3. Origins of calculation faults

By taking a closer look at the case of these small bridges, it is possible to find reasons for these differences:

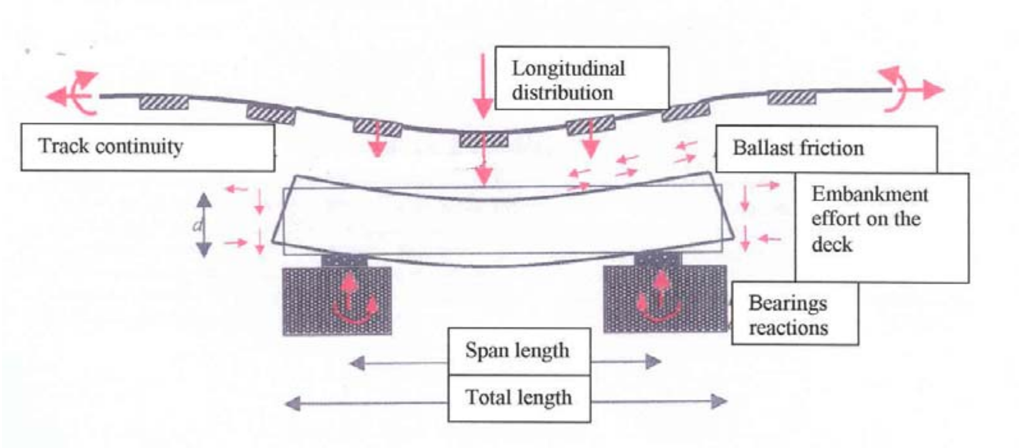


figure 2: Sources of errors

The real structural span is difficult to define because the impact of the size and the behaviour of the bearings are no longer marginal. The transversal behaviour, linked to the width of the bridge, also plays a role which becomes highly significant in the case of biais in the bearing lines. The behaviour of the slab must also be taken into consideration.

The cantilevered parts at each end also affect their dynamic behaviour by acting on the bearing conditions (more or less important level of elastic embedding) and on the manner in which applied forces will be distributed over the deck. Because of their environment:

The ends of the decks are more or less elastically embedded (particularly anchor blocks and/or embankment friction and/or ballast continuity).

The presence of the track, particularly with continuous rails, also modifies the behaviour of the structure and has an impact on load distribution (distribution through the ballast).

The vehicle-track interaction is also important.

The « damping » created by the bearing systems is no longer marginal.

A priori, we do not know the importance of each of these sources of errors with regard to the overall errors that have been noted.

4. Tentative correlation between calculations and measurements

4.1. Approach used:

It is based on the confrontation between measurements taken on real bridges and the results of calculation models. These models are progressively enriched to be as close to reality as possible.

4.2. Taking measurements

The dynamic measurements (acceleration at mid-span) were carried out by AVLS on 10 bridges, all being composite steel and concrete girder types spanning small distances. In particular, two decks were studied using an experimental modal analysis.

The list and characteristics of these bridges are summarised below.

Bridge	**KP77**	**KP101**	**KP102**	**KP109**	**KP112**	**KP116**	**KP225**	**KP333**
Span [m]	3.85	5.4	5.9	4.8	4.6	6.2	4.9	6
Length [m]	4.7	6.7	6.7	5.4	5	7	5.5	7
Width [m]	3.6	4.2	3.8	3.7	4.1	4.3	4.15	4.15
Deck thickness [m]	0.35	0.45	0.5	0.3	0.3	0.4	0.3	0.35
Number of girders	9	11	9	10	10	12	11	10
Type of beam	HN180	UB360	HN240	HN200	UC160	UB360	UC180	UC200 B

The two ends of these decks are tube anchored with mortar packing.

4.3. Frequency resetting

The first measure that naturally comes to mind consists in evaluating the important parameters that will permit the resetting of the bridge’s natural frequencies. A plate model was chosen for this modelling as, *a priori,* it presents a better spatial discretisation.

The study consisted in resetting the bridge models using the following parametric values:

- Stiffness (Young’s modulus),
- The bearing conditions: articulated and embedded

Attempted stiffnes resetting

A calculation using a more powerful modulus reveals that a Young's modulus of around 100 GPa (n=2) is necessary. Naturally, this value is unrealistic. The influence of the deck's stiffness cannot explain the high natural frequencies that were measured.

Resetting the bearing conditions

The following table summarises the measured and calculated frequencies of the tested bridges.

Frequency [Hz]	KP77	KP101	KP102	KP109	KP112	KP116	KP225	KP333
Measurement	43	25	18	20	23	25	23	20
Articulated bearing (calculation)	27	19	15	17	15	17	14	12
Embedded (calculation)	61	43	33	39	34	39	32	29

For the chosen stiffnes value (steel concrete coefficient equivalence: $\frac{E_s}{E_c} = n = 10$), the articulated bearing conditions systematically underestimate the natural frequencies, while the embedded conditions considerably overestimate them.

The calculations revealed that it was necessary to combine the effects of a vertical bearing stiffness with a rotation stiffness in the vertical plan (transversal axis rotation stiffness).

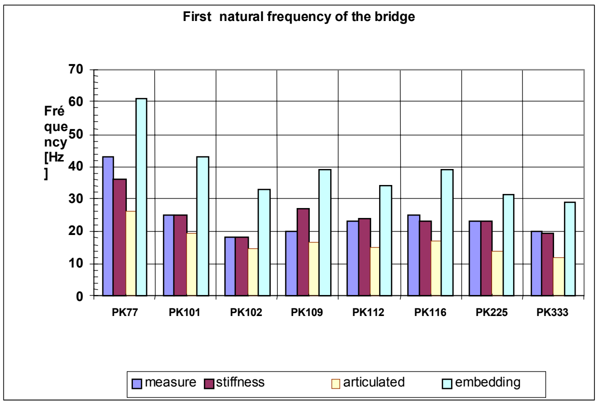
These stiffness were introduced into the model in the form of individual springs placed under the secondary beams.

To find the best adapted bearing conditions, the sensitivity matrices of the first two modes were calculated for bridge KP112, and different vertical and torsion stiffness were introduced.

The resetting was carried out using the stiffness values that permitted the resetting of the first mode at around 23 Hz and the second at around 31 Hz.

Values obtained: Vertical stiffness Kver=5.10^{E}8 N/m, torsion stiffness Krot=5.10^{E}7 Nm/rad

These bearing conditions were used for all other bridge models and gave the following results:



It can immediately be seen that resetting with elastic bearings gives the best results**.**

In addition, the resetting, which was only carried out on one bridge, permitted the resetting of the other bridges.

This demonstrates that frequency resetting requires the modelling of the elastic bearings.

Figure 3 : Comparison of various boundary conditions

5. Study of the influence of the main parameters having an incidence on the behaviour of short bridges

5.1. Chosen hypotheses

The sensitivity study was carried out using beam models with the following notations:

bridge span L [m], bridge length L_e[m], linear density m [kg/ml], EI module [Pa.m^4], vertical bearing stiffness k [N/m], bearing torsion stiffness c [Nm/rad], natural frequency f_0 [Hz], damping ζ [%], convoy speed v [km/h], wavelength $\lambda=v/f_0$ [m].

5.2. Sensitivity of bearings

Influence of bearing stiffneses

As above, the study of the influence of bearing stiffness was carried out using the sensitivity matrix of the first natural frequency on the vertical and torsion stiffness at the end of the beam. In order to generalise the results, all the variables were standardised:

Reference k_0 vertical bearing stiffness $k_0 = \frac{EI}{L^3}$ [N/m], reference c_0 bearing torsion stiffness $c_0 = \frac{EI}{L}$ [Nm/rad], reference $f_{réf}$ natural frequency $f_{réf} = \sqrt{\frac{EI}{mL^4}}$ [Hz].

By varying the stiffness values to cover all possible bearing situations, one obtains (by analysis of modal curves):

k/k_0	**$c/c_0<2$**	**$3<c/c_0<100$**	**$c/c_0>1000$**
<100	$f_0 \ll f_{réf}$ Rigid body modes	$f_0 \ll f_{réf}$ Rigid body modes	$f_0 \ll f_{réf}$ Rigid body modes
$100<k/k_0<10^3$	Combination of bending and rigid body; articulated type bending	Combination of bending and rigid body	Combination of bending and rigid body; articulated type bending
$10^3<k/k_0<10^4$	Asymptotic value of the natural frequency $f_0/f_{réf}=\pi/2$: articulated bearing	Intermediary situation between the articulated bearing and embedding	Bending dominates, asymptotic value of the natural frequency $f_0/f_{réf}=3.57$: embedding

The problems consists in finding a pair of values c and k that permit the model to be reset.

The k and c values are imposed by the bearings and (or) the soil conditions.

Calculation of bearing stiffneses

This part represented a first approach aiming to estimate the stiffness at the end of the deck.

The vertical stiffness result from the contribution of: the bearing stiffness, the friction over the depth of the embankment, the track continuity between the deck and the embankment.

The torsion stiffness concerning the transversal axis result from the contribution of: stiffness of the ground at the end of the deck over thickness d, the bearing stiffness, the track continuity.

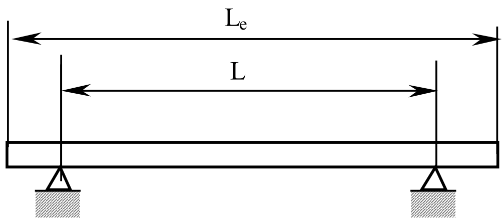
These stiffness were estimated and led to the following results:

It would seem that one fairly easily finds oneself in the zone where $k/k_0 > 500$. The frequency variations can be summarised by studying the c/c_0 relationship (the greatest difficulty lies in estimating the torsion stiffness).

Elastomeric bearings: no rotation stiffness effect; the calculated frequencies must be similar to the measured frequencies.

Anchored bridge: influence of the rotation stiffness: the frequencies must be increased.

5.3. Influence of the span/length relationship



This L/L_e relationship has little influence on the value of the natural frequency on condition that the length does not exceed 30% of the span.

However, problems might arise where excitation is concerned: as the bridges are very short, the response is determined by the transients generated at the deck entrance and exit.

Figure 4: notations

The results of the calculations carried out revealed the absolute need to model the ends of the deck when the L/L_e span/length relationship is less than 0.9.

5.4. Longitudinal distribution

The incorporation of this effect only concerns calculations made without track modelling.

The modelling presented in §6 integrates this effect.

6. Software modelling: DynPoCou

The SNCF bridge infrastructures department decided to have AVLS develop software to systematically study the dynamic behaviour of bridges. This software, DynPoCou, makes it easy to create a deck model by entering the bridge's characteristic parameters, such as its geometry, construction materials and bearings to model the track. Using ANSYS®, the software creates a model using the finished elements of the bridge being studied. It takes into consideration:

- the materials
- the type of deck (composite steel and concrete girders or reinforced concrete slab) and all its geometry (the deck ends, the cantilevers, etc.)
- the bearings (movable bearings, mortar packing or bearings entirely defined by the user to, for example, take torsion stiffness into account)
- the track (particularly its continuity, the stiffness of the sleepers, the type of rail, etc.).

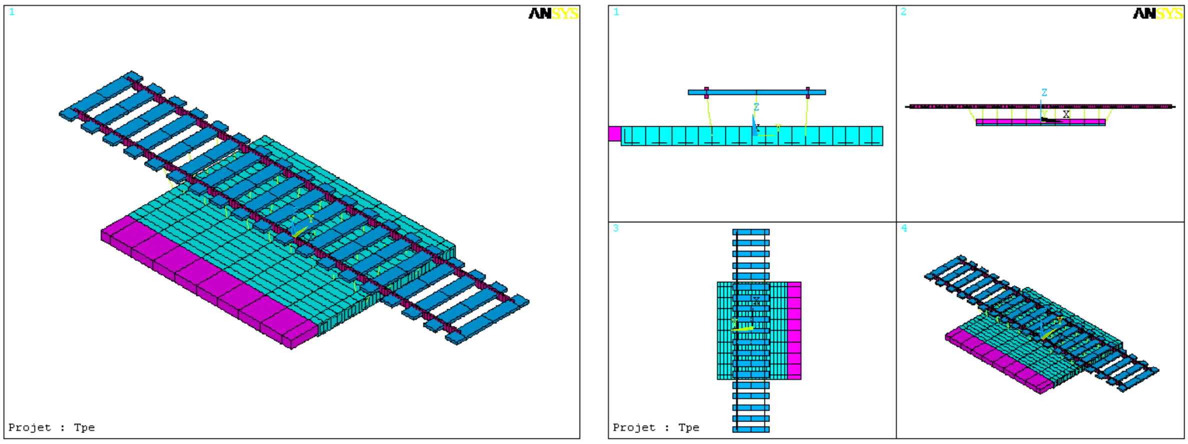


Figure 5: DYNPOUCOU Modelisation

DynPoCou uses a plate modelling for the deck, and the rails and sleepers are also treated as plates. The link between the track and the deck is created through the use of springs in order to model the ballast.

The limit conditions are either pre-programmed values or are manually entered by the user. They are applied to each of the structure's bearing nodes.

The model's discretisation parameters (grid detail) are automatically calculated by the software.

The effect of movable loads on the structure consists of the passage of a single axle to which is applied a linear combination in order to obtain a model of the concentrated forces representing the train. If the unitary response is carried out using ANSYS®, obtaining the response for a complete convoy is carried out by convolution using MATLAB to reduce the calculation time.

While simple to use, DynPoCou takes into consideration most of the above-mentioned criteria.

7. Correlation between models and measurements

The calculations were carried out for the tested bridges and gave the following results (without taking the load distribution effect into account, and only for the bridge KP77):

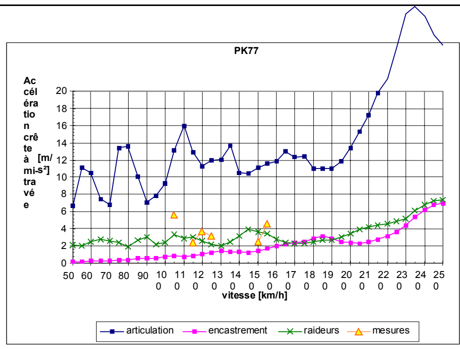
Bridge	Remarks	Accelerations
KP77	Very high overestimation of articulated bearing levels, underestimation for embedding. Acceptable levels for elastic bearings.	 Legend : Acceleration at mid span according to speed Articulated Embedding Stiffness Measure

Figure 6: Calculated acceleration / measured acceleration

8. Conclusions:

The elastic bearings models provide fairly satisfactory results.

The DYNPOCOU programme permits rapid calculations to be easily carried out.

The difficulty remains the correct appreciation of the bearing stiffness values.

Additional studies accompanied by tests are necessary for the precise calculation of parameters for bearing stiffness, and to characterise the influence of the track on different types of bridges.

In addition, the vehicle-bridge interaction effect remains to be quantified.

A research programme is developed to cover these latter points.

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